Circulation

Scottish Government
Riaghaltas na h-Alba
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Key message

The circulation in Scottish waters is strongly influenced by the ocean circulation of the adjacent Atlantic Ocean. The circulation changes due to a number of processes, including the tide, atmospheric conditions (wind and sea level pressure), seasonal heat input, changes in freshwater run-off, and variability in the North Atlantic Ocean.

Background

The ocean's large scale movements are mainly influenced by winds, differences in water density, sea level and planetary rotation.

The circulation around the Scottish coast is strongly affected by conditions and the ocean circulation of the adjacent Atlantic Ocean (Figure 1). The steep bathymetry of the continental slope acts as a barrier between the open ocean and shelf sea systems. Mixing processes between oceanic and shelf sea waters are complex and have a significant impact on conditions in Scottish waters.

Along the west coast, the influence of the land run-off from the estuaries and sea lochs significantly reduces the salinity close to the land, and thus impacts the circulation locally (Figure 1). In the northern North Sea, the Atlantic waters enter between Orkney and Shetland, around the north-east of Shetland, and through the Norwegian Trench (Figure 1). Along Scotland's east coast, these Atlantic water inflows in the northern North Sea, together with the influence of the Scottish Coastal Current, coming round from the west coast, set conditions and circulation close to the Scottish coast.

Several localised areas experience very strong tidal currents; these include the area between Orkney and Shetland, the Pentland Firth, off the Mull of Kintyre and Hebrides.

Knowledge of the ocean circulation is derived from a combination of centuries of observation-based oceanography and more recently the analysis of computer simulations of the ocean's dynamics.

Current drifters on deck MRV *Scotia*

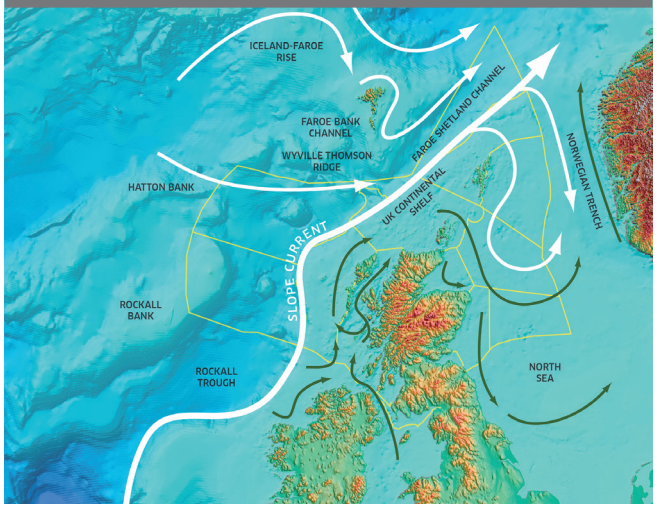

Figure 1.
Circulation map representing the general circulation pattern within the North Atlantic and North Sea areas. It should be noted that flow is not confined to these arrow tracks. Circulation of Atlantic water is shown by the white arrows, with coastal circulation represented by the green arrows. The outline of the Scottish Marine Regions and Offshore Marine Regions are shown by the yellow lines.

For further information on this topic go to: https://marine.gov.scot/sma/assessment/circulation

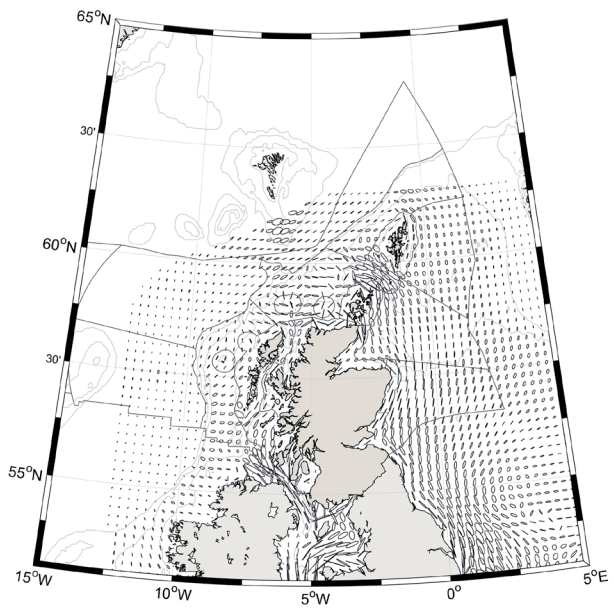

Figure 2.

The tidal currents from the principal lunar tide (M2) from the Scottish Shelf Model (De Dominicis *et al*., 2018). The currents are shown as tidal ellipses: this can be considered the trace of the tip of the current vector as it rotates through the tidal cycle. The ellipse's semi-major axis shows the main tidal current direction.

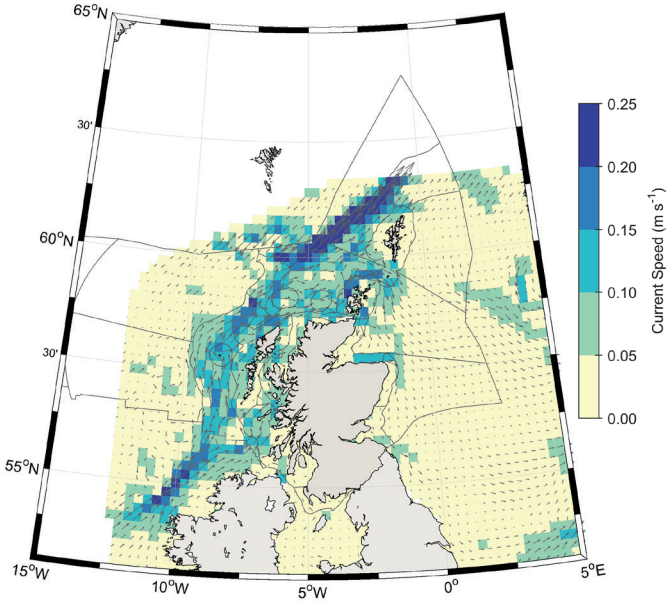

Figure 3.

The tidal currents from the principal lunar tide (M2) from the Scottish Shelf Model (De Dominicis *et al*., 2018). The currents are shown as tidal ellipses: this can be considered the trace of the tip of the current vector as it rotates through the tidal cycle. The ellipse's semi-major axis shows the main tidal current direction.

Results

Tidal currents

Tidal currents are driven by the tide generating forces due to the moon and the sun, which vary with different periods (constituents) due to different factors. These tidal constituents can be considered waves traveling through the ocean. Once they interact with large changes in the bathymetry, the tide is amplified (Figure 2). Tidal currents are also amplified in narrow passages, such as between the Scottish mainland and Orkney, and around headlands, such as the North East (Figure 2). In general, there is little to no net displacement of water due to tidal currents.

Residual currents

On average, the ocean currents around Scotland flow in a clockwise direction around the coast (Figure 3).

In regions close to the Atlantic Ocean and those where Atlantic-origin water masses are found (such as the northern North Sea), currents are influenced by those in the adjacent North Atlantic Ocean. Along the edge of the continental shelf (the region shallower than 200 m), the European Slope Current transports warm and salty Atlantic water northwards (along the boundaries between the deeper Rockall, Bailey and Faroe-Shetland Channel Offshore Marine Regions (OMRs) and the Hebrides, North Scotland and North & West Shetland Shelf OMRs). The steep bathymetry limits mixing between the oceanic and more coastal water masses present on the continental shelf.

The Faroe-Shetland Channel (FSC) is one of three regions where exchange between the Atlantic Ocean and Arctic Ocean (via the Norwegian and Greenland Seas) occurs.

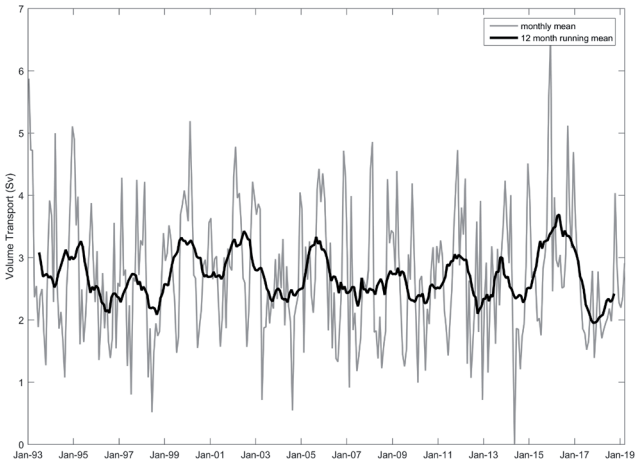

Figure 4.

The transport of Atlantic Water in the Faroe-Shetland Channel, expressed in Sverdrup (1 Sv = 1 million m^3s^{-1}), calculated from the sea surface height difference measured by satellite altimeter.

The time series of Atlantic Water transport in the FSC (Figure 4) shows a clear seasonal signal, and no statistically significant trend (Berx *et al*., 2013). Although the transport is not changing, the heat and salt content are, and this will have implications for conditions in the Arctic Ocean, as more heat and salt are brought northwards.

The coastal circulation around the coast and in the North Sea will show considerable variation through the seasons in both the strength and position of the currents. This is due to the influence of atmospheric conditions and due to narrow, relatively fast-moving currents (jets) associated with seasonal mixing fronts.

On the west coast, there is also a significant freshwater contribution from the land-run off via the large number of sea lochs and several large estuaries (particularly in the Clyde, Argyll, Outer Hebrides and West Highlands Scottish Marine Regions). Their contribution reduces the salinity of the Scottish Coastal Current.

The northern North Sea circulation is influenced by the inflows of Atlantic water to the region via three main pathways: between the Orkney and Shetland Islands (North Scotland Shelf and Fladen & Moray Firth Offshore OMRs), east of Shetland (East Shetland Shelf OMR) and along the edge of the Norwegian Trench. These currents form an anti-clockwise (cyclonic) circulation around the shelf sea, with most of the outflow occurring via the Norwegian Trench. At the southern end of the North Sea, a small inflow via the English Channel also occurs.

Conclusion

The general pattern of ocean currents and tidal currents in Scottish waters is well understood and has been described here. In general, currents transport water masses in a clockwise direction around the Scottish coast. The circulation is influenced strongly by conditions in the adjacent North Atlantic Ocean. Measurements of Atlantic Water transport in the Faroe-Shetland Channel show seasonal variability but no long term trend since 1993, although water mass characteristics are changing.

An assessment of the variability of currents is more difficult as direct observations are limited in space and time. Sustained observations of currents through in situ and remote sensing platforms are key, in addition to the integration of data outputs from validated computer simulations.

Knowledge gaps

The general circulation in Scottish waters is well understood. The main evidence gaps are sustained and high-resolution direct observations of currents in Scottish waters, particularly the exchange in the northern North Sea. There are new data products (e.g. from remote sensing and numerical models) and new (e.g. autonomous) technologies under development which could fill this data gap.

The Overturning circulation in the Subpolar North Atlantic (OSNAP) programme is expanding the knowledge of the Atlantic Meridional Overturning Circulation and therefore the variability of Atlantic water in the Rockall, Bailey and Hatton regions, but more work is needed on the drivers of circulation variability, particularly in light of climate change.

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